CANADIAN JOURNAL OF RESEARCH

VOLUME 23 APRIL, 1945 NUMBER 2

— SECTION C —

BOTANICAL SCIENCES

Contents

	Page
Oats and Climate in Southern Ontario—*M. B. Zacks* - - -	45
The Fluorescence of Frozen Potato Tuber and Apple Fruit Tissue Under Ultra-violet Light—*W. Newton and W. Jones* -	76

NATIONAL RESEARCH COUNCIL
OTTAWA, CANADA

CANADIAN JOURNAL OF RESEARCH

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For the present, each of these sections is to be issued six times annually, under separate cover, with separate pagination.

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Canadian Journal of Research

Issued by THE NATIONAL RESEARCH COUNCIL OF CANADA

VOL. 23, SEC. C. APRIL, 1945 NUMBER 2

OATS AND CLIMATE IN SOUTHERN ONTARIO[1]

BY MILDRED BROOKSTONE ZACKS[2]

Abstract

The effect of monthly rainfalls and temperatures during the growing season, upon the resultant yields of oats is studied by the correlation coefficient method and also by the isopract technique.

Cool, wet Junes and Julys are the most important features for high subsequent yields, the degree of significance of these varying, however, according to latitude and topography.

A system of 13 zones, each more or less homogeneous in these respects is discussed for the Southern Ontario region.

Suggestions for future improvement of varieties in the poorer areas, as well as for more reliable crop and climatic statistics is made.

The paper also contains a historical summary of similar work done elsewhere in the world, the results so obtained being contrasted with the present ones.

The problem dealt with in this paper was suggested by the lack of a climatic-agricultural atlas for Ontario, although an excellent one for the Prairie Provinces was published in 1931 (29). Other than the maps in References 5, 31 to 34, 40, 45, and 46, few detailed maps of this nature have been made for the longer settled Ontario. The zoning of crops is of vital importance to an agricultural area like peninsular Ontario. This study marks an initial attempt at solving the crop-zoning problem in the southern Ontario region. Oats were chosen because, except for hay and clover, they are the crop to which the greatest land area in Southern Ontario is devoted, the annual average for 1882 to 1937 being 2,422,228 acres with a market value of $36,097,763 (2). On an average, about 8% of the total area of Southern Ontario is planted to oats.

The correlation of oat yields with climatic factors is a practical problem (12). The crop in Ontario varied from 50,501,701 bu. in 1882 to 120,217,952 bu. in 1915. The yield per acre also fluctuates (2) from year to year, being 23.4 bu. per acre in 1921 and 45.1 bu. per acre in 1918, i.e., Ontario has an average per acre yield 100% greater in some years than in others.

Climate, the longer phase of weather is, without doubt, the dominant factor in limiting the yield of oats. Soil fertility, methods of cultivation, and varieties of seed used have less effect upon the year to year variation in yields.

[1] *Manuscript received in original form February 18, and as revised, November 21, 1944.*

Contribution from the Department of Geography, University of Toronto, Toronto, Ont. A condensed version of a Master of Arts thesis accepted by the Department of Geography in May, 1940.

[2] *Formerly Miss Mildred Brookstone, Instructor, Department of Geography, University of Toronto.*

Thus rain and temperature in their various phases in Ontario should manifest some interesting effects on the yield of oats there. The production in any year is the result of the interaction of many factors of nature—some favourable, others unfavourable. The purpose of this study is to determine what weather conditions affect these yields and in what month of the growing season they have their greatest effect. There has been a considerable amount of work done on this problem from the agronomist's point of view, the method being to calculate the correlation coefficients between yield and climatic factors (usually precipitation and temperature) for a particular station, over a period of years. The present work is intended to show the variation in the relative importance of the different factors, according to the geographic position. That is, while July temperatures may be important in the counties throughout the middle of Southern Ontario, the period of dominance may be advanced or retarded according to the position of the county south or north, respectively, of this line.

The General Problem of Crops–Climate Relationships

As long ago as 1918, Brooks (3) compiled a list of 50 topics for research in meteorology, of which one was "Correlation of Weather and Crops—Mathematical Correlation of Monthly Mean Temperature and Total Monthly Precipitation with Crop Yield." Even prior to this, as well as subsequently, various studies have been directed along these lines (1, 9, 10, 15 to 27, 37 to 39).

Owing to inadequate and unsatisfactory data, valid forecasts of climate–yields beyond the period covered by the original statistics have been rare. Some 25 years ago J. Warren Smith of the United States suggested a joint attack on the problem by the Weather Bureau and by the State Agricultural Experimental Station, but unfortunately illness prevented him from initiating this. The British Meteorological Scheme has been at work on the problem since 1924 from the four phases—meteorological, agricultural, horticultural, and phenological. In the U.S. Department of Agriculture since 1936 two lines of attack have been used,—

(a) 'Extensive' studies of weather–yield relationships on a geographical area basis. This is the method used in the present study; it was earlier employed by Rose (36).

(b) 'Intensive' approach utilizing crop–weather data for agricultural experimental stations, as used by Irvine (30). In this type, the yield data are obtained from carefully conducted experiments and correlated with weather data recorded at the same location, so that better prognostications of yields should be possible. However, one thus loses the geographical variations. For this reason, it was thought wiser to use method (*a*) in this study.

Importance and Varieties of Oats

Canada is the fourth ranking producer of oats, and Ontario produces nearly 25% of the total for the Dominion. In addition, in Ontario and other eastern

provinces the oat crop takes first place in total value among grain crops. A cool and moist climate is necessary for the oat crop, but poorer soils and little care in soil preparation are of minor importance compared to the more rigid requirements of wheat and barley. The oat does best, however, on relatively moist soils that do not dry out quickly, e.g. clay and clay loams. In Southern Ontario soil fertility is not generally a yield-limiting factor, since the natural fertility has not been lost by leaching, erosion, or cultivation for a long succession of years. Under such conditions, weather factors, particularly rainfall and temperature, will limit the crop yields.

Peninsular Southern Ontario extends from latitude 42° to 46° N. so that only spring varieties of oats are involved in this problem. The commonest varieties here (6, 7) are:

Early maturing (96-100 days)	Medium (100-104 days)	Late maturing (110-113 days)
Alaska	Erban	Banner*
Cartier	Vanguard	Victory*
O.A.C. 3		O.A.C. 72

*Most popular.

The early maturing varieties must be used where the land is late for seeding (north), and when an early crop is desired to avoid heat waves in the late season (extreme south). In addition, soil conditions, prevalence of oat diseases, etc. must all be considered in choosing the variety best suited to the conditions of a given locality.

Past Work on Oats

The work on this subject has dealt with several rather widely separated regions. Hooker (13) considered eastern England. His results agree closely with those obtained by Smith (39) in United States. He concluded that spring and summer are of preponderating importance, seed-time being unimportant. Fifteen years later Hooker (14) reworked his data for the longer period of 35 years. His earlier results were toned down although no major modifications were necessary. He found cool weather from April to August to be essential and the best yield of oats occurred in a season that was uniformly favourable. Geddes (11), dealing with the three northeast counties of Scotland, concluded that there oats require a mean temperature above the normal, particularly during the sowing period and for some weeks immediately before harvest. The crop in Eastern England, on the other hand, was shown by Hooker (13, 14) to require a cool summer. It appears, therefore, that to obtain best results with oats a mean temperature lower than that of southeast England and higher than that of northeast Scotland is necessary. Geddes also found that a summer rainfall above the normal is a favourable factor. It is of interest to note that the eminent Sir Napier Shaw pointed out the fact that the work of Hooker and of Geddes served to show that the application

of this method to a number of regions would serve to locate the area of optimum conditions, i.e., the geographical aspect was hinted at.

Roberts (35) in his study of oats at Bangor on the north coast of Wales, established no correlation between yield and total rainfall or total accumulated temperatures for the growing season. The region studied is somewhat similar to Southern Ontario in that the soil is a stony, heavy loam, mainly derived from local glacial drift of shaly character. The climate, however, differs radically, being of typical western marine character.

In Germany, C. von Seelhorst (quoted by Roberts (35)) found that for oats a marked need of water comes at the end of May and the beginning of June and after that it quickly increases. W. Brouwer (quoted by Roberts (35)), dealing with an inland continental area in Germany somewhat similar to Southern Ontario, found positive correlations for moisture and yield of oats at all stages of growth in the plant, showing that oats are favoured by moisture. The values of the correlation coefficients, however, were never big enough to show a high significance. The distribution of rainfall was shown to be more important than the total amount. However, he found temperatures significantly negative. Increase of temperature, whether measured by maximum, minimum, or average temperature, results in a decreased crop and vice versa.

In the United States, Wallis (44) suggested that the best four states for oats—Iowa, Illinois, Indiana, and Wisconsin, have a growing period of $3\frac{1}{3}$ to 4 months and a rainfall of 13 to 15 in. in that interval. Another American, J. W. Smith (39), pointed out that oats are grown within a belt where the mean annual temperature is between 28° and 68° F. The region under consideration here falls within the annual isotherms of 38° and 48° F., i.e., well within the limits set. Smith points out that notwithstanding the fact that oats are a cool weather crop and that spring oats should be seeded as early as practicable, the temperature should be above normal for the season and the locality, and precipitation should be less than normal for best conditions of seeding and germination of the grain. While heads are forming, however, and grain is being developed the crop must have cool and moderately wet weather for best yields. Cool weather is favourable to filling of the grain. Visher (43), another American, has dealt with corn, wheat, and oats in Indiana in a qualitative way.

In Russia, Brounoff (quoted by Smith (39)) found that the critical period for oats as regards moisture is within the 10-day period before heading (the end of June).

Griffith Taylor (40) has pointed out that for Southern Ontario the distribution of oats is unfavourably affected by the Precambrian Shield. The optimum runs along the middle of the agricultural belt, the chief control being the July isotherm of 68° to 69° F., rather than the total annual rainfall, despite a certain similarity between the oat isopleths and the summer isohyets.

Finally, the only detailed work on oats in Ontario has been done by Irvine (30) at the Ontario Agricultural College, Guelph. He studied some seven

varieties, correlating them with average daily temperature, the average daily maximum temperature, and the average daily minimum temperature for each month of the growing season, also with the precipitations of each of these. Then partial correlations between yields and average daily temperatures, eliminating precipitation, and those between yields and precipitations, eliminating average daily temperatures, were worked out. Coefficients for average temperatures were mostly negative. With precipitation, in nearly all cases, the coefficients for April and May were negative, while those for June, July, and August were positive. As for the maximum and minimum temperatures, the coefficients are again mostly negative indicating a decrease in yield if either unusually warm days or nights occur.

The Region Studied

Southern Ontario is a triangular area of 50,000 sq. mi. The study of this peninsular section of Ontario (omitting Algonquin Park) was considered a fairly promising one since variations in yield, precipitation, and temperature are sufficiently great to suggest a possible link between them. This mosaic of glacial and lacustrine plains consists of two upland regions in the western and northeastern sections, and the lowland areas along Lake Ontario, with the rest between these two extremes in height. We therefore find areas of Precambrian Shield and of plains of limestone and shale over which developed the Silurian Niagara Cuesta (33). Great changes are to be observed in the topography of certain counties with the Shield in the north and lake plain in the south, also in Halton, which the Niagara Cuesta crosses in a north–south direction. It is obvious that the distribution of crops under these circumstances will be anything but homogeneous; however, this matter had to be adjusted as well as possible in drawing the isopleth maps.

Crop Statistics

The oat yields used were those published by the Ontario Department of Agriculture (2) for the individual counties. It was originally planned to use data for townships in which meteorological stations were located, but this was found to be impractical because of lack of continuity in both sets of records. There were other unsatisfactory features about these data but as they were the only ones available they had to be employed.

Choice of Weather Factors

Since the northern boundary of the winter oat region is roughly along the mean winter isotherm of 35° F., all oats in Ontario are of the spring-sown types, hence winter climatological considerations were omitted. Also, in a region such as this, where rainfall and temperature fall well within the optima set for oats, viz., 13 to 15 in. and mean annual temperatures of 28° to 68° F. (39, 44), it is obvious that weather factors prior to planting are relatively unimportant (see coefficients for yield and April weather to substantiate this). The factors considered were mean monthly temperatures and total precipitation for April, May, June, July, and August. Despite the fact that it was

known that periods shorter than a month should be used, it was impossible to do this owing to lack of phenological data, e.g., time of heading, stooling, etc. Also, a period of at least 35 years should be considered in order to have all possible types of weather for the given station included. Unfortunately, the data for the stations used varied from 12 to 25 years, since it was necessary to eliminate some of the older data in order to use the method of weighting explained below.

Soils

As the published work on the soils of Southern Ontario (5, 31) is limited to only a section of the region under investigation, it was decided to omit this factor from consideration, except in a very general way. In addition, for units as large as counties there may be many types of soil, which makes it difficult to attribute observed average conditions to any one of these classes. The soils include clay loam, loam, sand, organic, and shallow soils over igneous rocks in the north. Clays and clay loams are the most suitable soils for the production of oats, since they are less dependent on the proper distribution of rainfall during the growing season. The region studied is thus well favoured as regards the type of soil, except in the northern areas.

The Statistical Technique

The method employed was, with certain modifications, that of Dr. John K. Rose (36*) who was, I believe, the pioneer in the application of methods of correlation analysis to geographical areas, rather than to individual experimental stations, as is done by the agronomist. Weighting was done by the method of Thiessen (41).

The correlation coefficient (r) measures the tendency of two variables to increase or decrease together if r is positive, or the tendency of one to increase while the other decreases if r is negative. Its range is from $+1$ through 0 to -1. It is to be noted that the correlation coefficient in itself in no way expresses causation. The interpretation of such a fact must be made from knowledge of the problem. Also, the value say $+.78$ is to be interpreted only as a measure, not a percentage. Examination of some 30 dot charts, out of the 400 correlations done, showed that linear correlation was apparently more likely than non-linear, hence it was assumed that this would hold for the remainder of the cases.

Tuttle and Satterly (42) and Ezekiel (8) suggest that if the coefficient is less than the probable error, there is no correlation, but when r is greater than six times its probable error (*p.e.*) we may be practically certain that the two phenomena are not independent of each other; if the *p.e.* is small, correlation is well marked if r is greater than .5 and poor if r is less than .3. Thus for our purpose the following rules were adopted,—

r below .3—insignificant correlation,
.3 to .5 —barely significant correlation,
r above .5—quite significant correlation.

* *See also Ph.D. thesis, University of Chicago, 1935.*

The relationships found were those that actually existed during the given period, but we are usually in a position to say only that the same relationship *probably* holds generally (i.e., in the past and future). Besides the magnitude of the coefficient, a sort of geographical test was applied, i.e., values that were of different sign and magnitude from those of adjacent counties were regarded with suspicion, unless some unusual condition of topography, soil, etc. existed to which this difference could be ascribed.

Oat Yields

The yields are highest in the extreme southwest in the Leamington and Essex–Kent areas and in the southern Western Uplands; they are least in the vicinity of the Shield–Frontenac Axis, also in Welland county (Fig. 1).

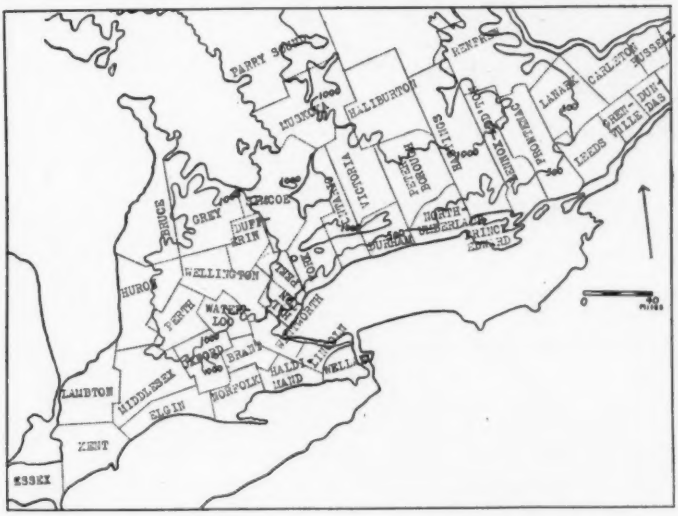

FIG. 1. *Index map of counties of Southern Ontario with contours added.*

Oats are concentrated along Lake Huron and in the eastern counties, while there are least in the Shield–Frontenac area (Fig. 3). On the whole, the isopleths for yields and distribution (Fig. 2) follow the same general areal pattern except that the yields are not as great in the eastern counties as the area allotted to them would suggest. However, the Ontario farmer is following fairly closely the dictates of nature in his assignment of land to this crop.

Oat Yields and Temperature

Only the mean monthly temperatures for April, May, June, July, and August have been considered in this preliminary study (30).

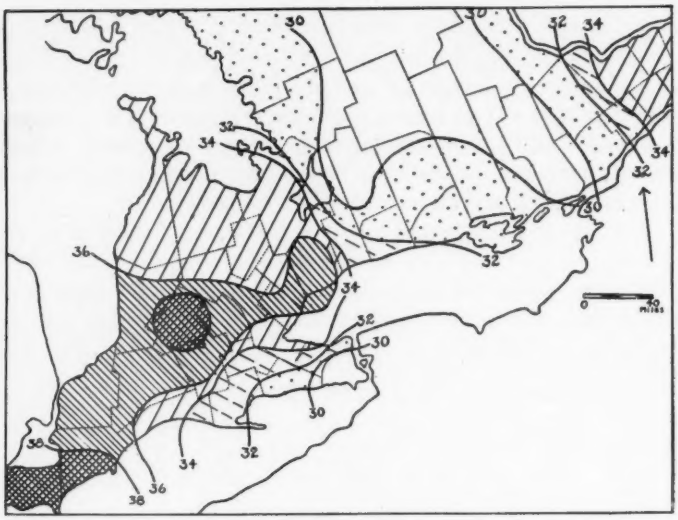

FIG. 2. *Oat yields in bushels per acre.*

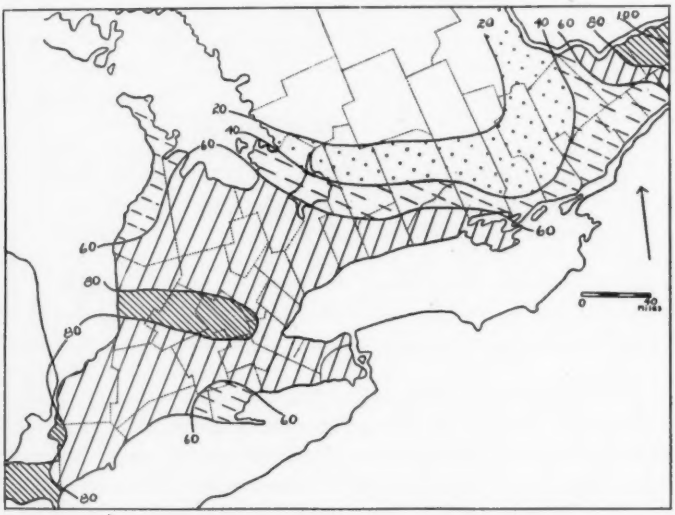

FIG. 3. *Oats in acres per square mile.*

April (Fig. 4)

It has been shown (34, 40) that the average date of the beginning of the growing season (above 42° F. mean temperature) varies from April 5 in the Harrow–Leamington area to April 26 in the northern Haliburton area, a

difference of three weeks. It is to be expected, therefore, that the correlation coefficients between April mean temperatures and yields will be highest in the northern area, where the arrival or non-arrival of the required growing temperature is of prime importance. In years when the temperature for early April is above normal, yields may be expected to be much above the average.

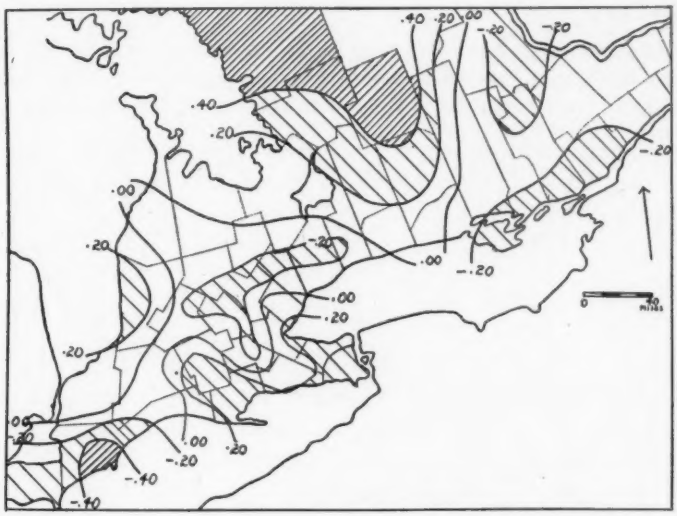

FIG. 4. *Simple correlation coefficients, oat yield with April mean temperature.*

The isotherms range from 45° in the Harrow-Leamington area to 37° in the northern part of Parry Sound. Attention is also called to the 44° isotherm in Welland, which suggests that the Niagara Cuesta constitutes a topographic barrier with some influence on temperature during the month of April. Thus, the isotherms have their general east–west character somewhat modified by topographic influences.

As expected, there is an important influence of April mean temperatures on yield in the northern region, the correlation coefficient being greater than $+.40$. This is the section where there is a marked decrease both in yield and in weight per bushel when the seeding of oats is delayed. The slightly negative values in southwestern Ontario are too small in magnitude to be considered significant, however they do suggest that temperatures below normal at the time of seeding are favourable in the warmest part of the province.

Irvine (30) found an average value of $-.14$ for Wellington county, while the present method gives $-.22$, which agrees fairly well. This suggests that the method adopted gives results comparable with those obtained at isolated

Experimental Stations, the observed difference being easily attributable to the different lengths of periods used in the two cases.

Thus, in the north, significant positive coefficients occur in the area of mean April temperature below 38°. In the north the higher the April temperature of a particular year, the better the yield; while in the southwest poorer than average yields occur after April temperatures above average.

May (Fig. 5)

The isotherms range from 56° in the extreme southwest to 51° in the north, and are roughly in an east–west direction. The region is 12° to 13° warmer than in April, but the pattern of the isopleths is essentially unchanged.

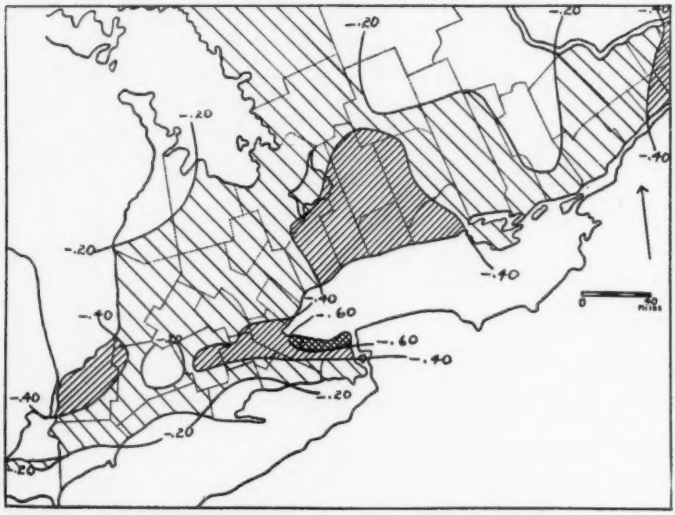

FIG. 5. *Simple correlation coefficients, oat yield with May mean temperature.*

The simple correlation coefficients between yield and May mean temperatures are all negative, but are too small to be considered significant, except around the western end of Lake Ontario (the topographic effect of the Cuesta) and on the eastern shore of Lake Huron (possibly linked with precipitation). Again, close agreement was found with Irvine's results (30). Hence for high yields of oats a mean May temperature below normal is necessary. By this time practically all seeding has been done and the oat plants, at various stages of growth throughout the area, require low temperatures if high yields are to result.

June (Fig. 6)

The June isotherms range from 67° in the extreme southwest to 60° in the north, travelling roughly in an east–west direction. Certain topographic

effects are seen in the irregularities of the isotherms, e.g. the cooling effect of the Western Uplands and the northeastern uplands is evident, also the influence of the Niagara Cuesta.

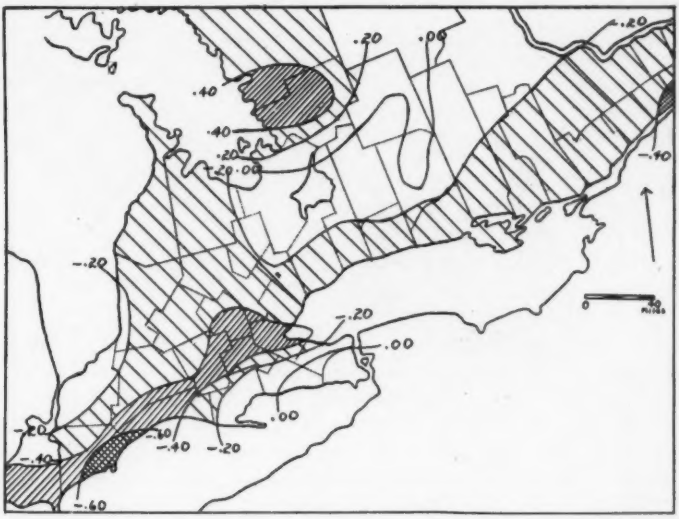

Fig. 6. *Simple correlation coefficients, oat yield with June mean temperature.*

The southern region has negative correlation coefficients, while the north is slightly positive, showing that the stages of growth differ considerably as one moves northward. A cool June seems necessary for high yields.

July (Fig. 7)

The July isotherms range from 72° in the southwest to 66° in Parry Sound. The cooling influences of Georgian Bay and the upland areas of Western Ontario and Renfrew are apparent.

A large area of significant negative correlation now exists. Of the five months of growth, July would appear to be the most critical as far as temperature is concerned, in determining subsequent yields of oats.

August (Fig. 8)

The isotherms follow the same areal pattern as for the preceding months, the temperatures being some 2° cooler than for July. Nowhere is there a significant correlation coefficient for August temperatures, the values lying between $-.20$ and $+.20$. It seems unwise to ascribe any importance to August temperatures, but had weekly averages been available it seems logical to suppose that more significant coefficients would have been obtained, especially in the north where warm periods for the middle of August might mean the difference between success or failure of the oat yields. This is

borne out by the fact that the regions of highest positive correlation occur in the upland areas of the northeast.

As suggested by Wallis (44) the growing period in Ontario averages about $3\frac{1}{2}$ months, so that oats sown the end of April would be reaped the first part

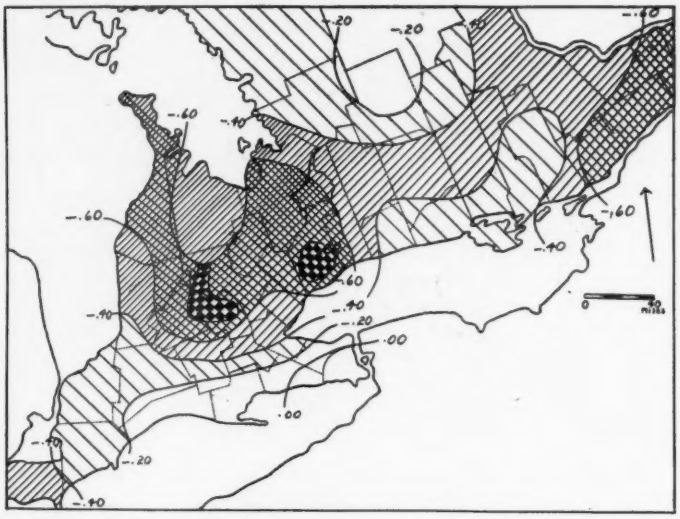

FIG. 7. *Simple correlation coefficients, oat yield with July mean temperature.*

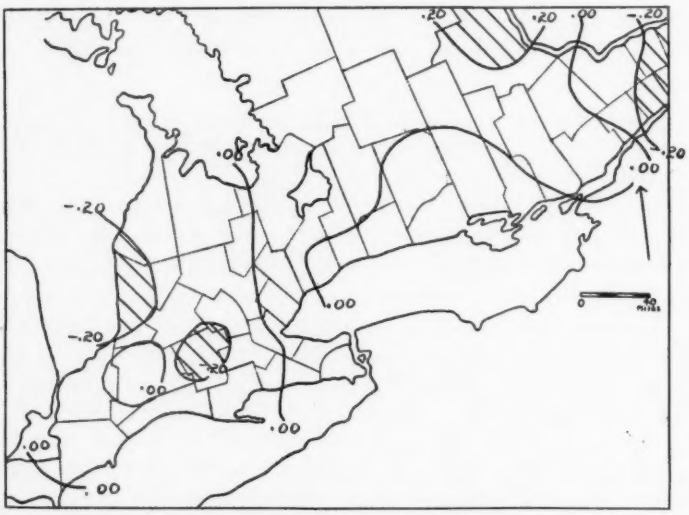

FIG. 8. *Simple correlation coefficients, oat yield with August mean temperature.*

of August. However, since such short-season varieties as Alaska are commonly used in the Parry Sound area, reaping is advanced as much as two or three weeks, but sowing is retarded. Thus in that area for August the significant coefficients for the early part of the month have probably been masked by the neutral effects of the latter part. We may conclude that temperatures of August *as a whole* are of little importance in determining the yield of oats in Southern Ontario.

Oat Yields Correlated with Precipitation

In the absence of soil moisture data rainfall was chosen as the best indicator of available soil moisture. The correlation of rainfall and yields on an extensive basis introduces many errors that are not encountered in the correlation of soil moisture and yield on experimental plots. In the first place, rainfall is recorded for the most part at only one location in each county. Frequently the gauge is not located in the central part of the county, and its position may be changed at intervals. The reading from the gauge gives only a poor indication of the character of effectiveness of the precipitation for the county as a whole. Furthermore, slope and topography vary from county to county so that run-off varies a great deal from section to section. In addition, estimated yields on an extensive basis may show more variation than accurately determined plot yields. However, up to the present time rainfall is the most reliable indication of soil moisture that is available on an extensive basis. The method of weighting (41) was employed.

Only one phase of precipitation, the total monthly amount, was correlated with oat yields in this study, the figures for April, May, June, July, and August being investigated.

April (Fig. 9)

The precipitation increases as one moves inland from Georgian Bay, being greatest along the shore of Lake Erie, the range being from 2.4 to 3.4 in. This is largely the result of cyclonic activity along the Great Lakes.

It is instructive to consider the variability of this precipitation, i.e., the standard deviation from the mean monthly precipitation, expressed as a percentage of that mean. The higher the percentage the less reliable is the rainfall. Regions with high variability will be victims of drought in bad years and their crop production will fluctuate widely. In India a deficiency in rainfall of 25% during the months June–September will cause injury to crops, while a deficiency of 40% will spell ruin, whether the rainfall be 12 or 50 in. We may expect that such an effect will be observed in Ontario, too, though on a less marked scale because of lower temperatures here.

For April the values range from 60 to 30%. The high figures are explained by an examination of Putnam and Chapman's maps (34) of the "Number of Rainy Days" (0.01 in. or more per day) and of the "Drought Frequency" (less than 1 in. per month). Since in some months there may be no precipita-

tion in a given year, while in others there may be 10 in., it is obvious that the net result will be a high percentage of variability for the monthly precipitation.

There is only a small area on the north shore of Lake Ontario with significant coefficients. It also had a high coefficient with April temperatures. In general, excessively wet periods in April are unfavourable for high yields of oats, i.e., seeding is best done during relatively dry periods.

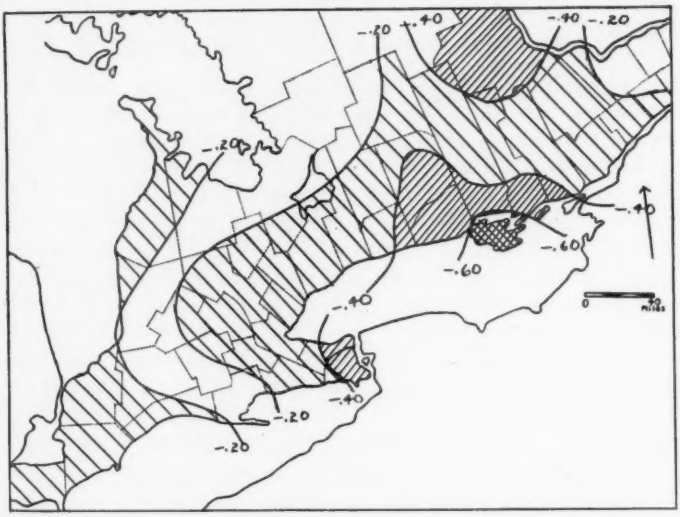

FIG. 9. *Simple correlation coefficients, oat yield with April precipitation.*

May (Fig. 10)

In the isohyetal pattern the effect of the Western Uplands in increasing the rainfall is again in evidence, also the 'rain-shadow' effect of the Niagara Cuesta. The extreme east is once more a region of high rainfall. On the average, May is considerably drier than April, particularly in the Lake Erie counties.

Only in the extreme eastern area do we find significant correlation coefficients, these being negative. There is also a region of fairly high negative values in the extreme southwest. Thus while high negative coefficients are linked with high rainfall in the east, they are associated with low rainfall in Essex. It will be shown below by the isopract method that Essex and Kent counties differ so much in climate from the rest of Ontario, that they are better considered as part of the United States Corn Belt.

Thus for May, precipitation is somewhat less important to yields of oats than is April rainfall, that is, during and immediately after seeding the rainfall is more important than it is later on. The fact that the coefficients, though small, are positive along the Erie–Ontario shorelines suggests that there the

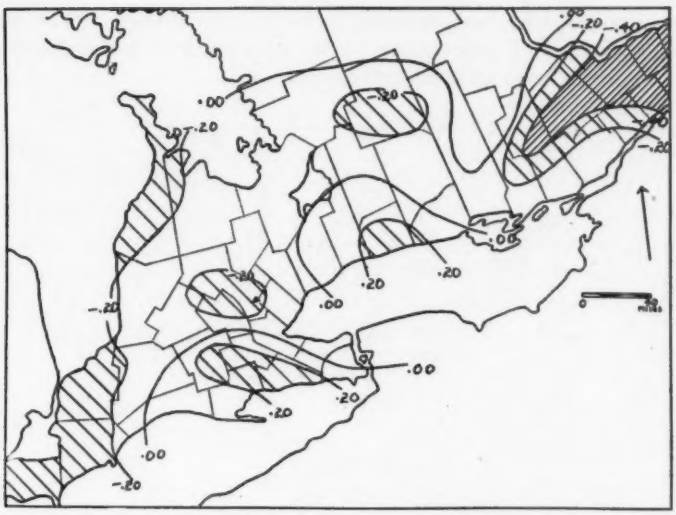

FIG. 10. *Simple correlation coefficients, oat yield with May precipitation.*

plants have reached a stage of growth where heavy rainfall is favourable, while they are still in the less advanced stage elsewhere.

June (Fig. 11)

Again the upland and eastern counties have the highest rainfall. The correlation coefficients are significant and positive in three areas—south of Georgian Bay, north of Lake Erie, and the Renfrew region. Practically all the values are positive, except for slightly negative ones in the extreme east. For extent of significant coefficients, precipitation for June is more important than it is for any other month. A June rainfall above normal is favourable for high yields of oats.

July (Fig. 12)

The isohyets range from 2.2 in. in the southwest to 3.4 in. on the Western Upland, with dry areas also in Prince Edward county and on the north shore of Lake Erie. Thus there is less rainfall over the lakes than on the inland areas sloping upward from them. The eastern counties are again relatively wet.

The correlation coefficients are significant in a relatively large area just along the shore of Lake Ontario. The values are slightly negative in the Essex–Kent area, and are relatively low everywhere except in the region named above. Thus July rainfall is important only along Lake Ontario, and should be above normal for high yields of oats to result. The area of significance is fairly far north and has relatively low July precipitation. Apparently the oats are at a critical stage of growth for which the normal amount of rainfall is not the optimum one. Although the rainfall is even less in the

southwestern counties, because of the earlier planting the oats will have passed this critical stage of their growth, hence the coefficients are relatively insignificant, even becoming slightly negative.

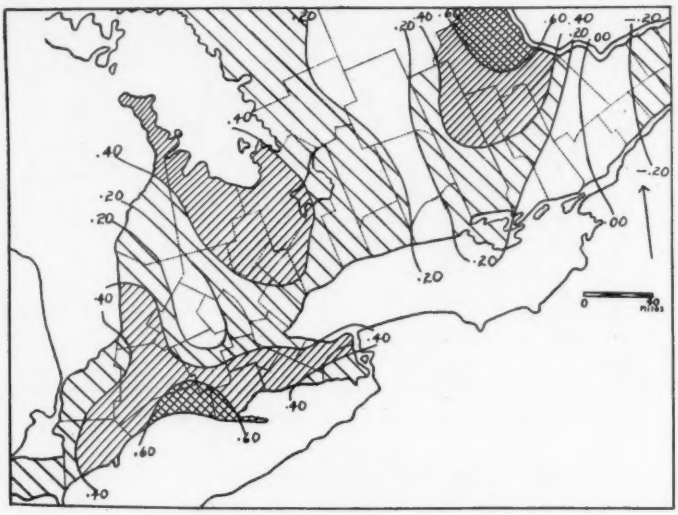

FIG. 11. *Simple correlation coefficients, oat yield with June precipitation.*

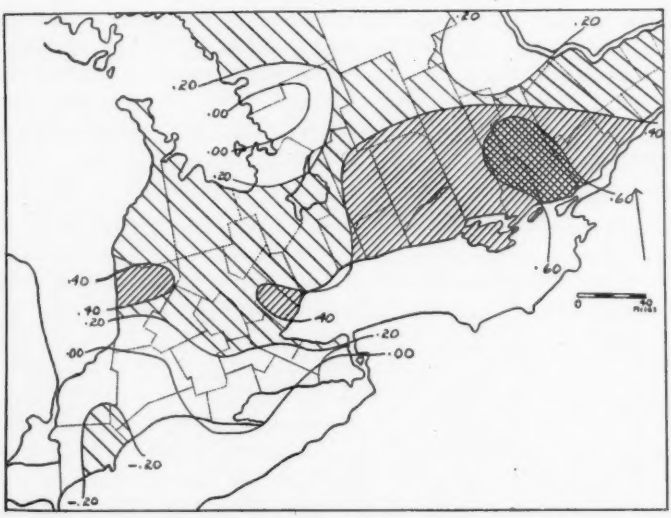

FIG. 12. *Simple correlation coefficients, oat yield with July precipitation.*

Thus, in the drier, more northerly parts of the province July precipitation is a critical factor determining yield. One would expect that the stage of growth in, say, Frontenac in July, would be the same as that in say, Norfolk in June, hence the similarity of their coefficients for these two periods, respectively.

August (Fig. 13)

The precipitation ranges from 2.0 in. in Welland to 3.2 in. in the extreme east. As in July, dry areas occur around Georgian Bay, in Essex, in Welland, and in Renfrew, while the Western Uplands and the extreme eastern counties are the favoured regions. The rainfall is considerably less for August in general, than for the four other months considered.

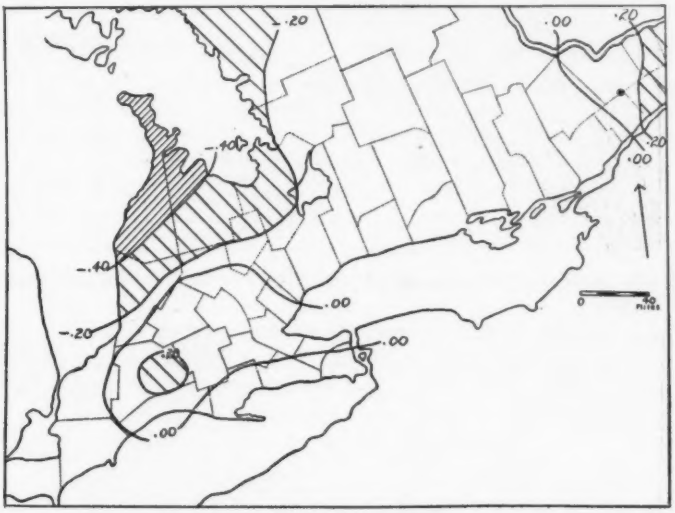

FIG. 13. *Simple correlation coefficients, oat yield with August precipitation.*

The correlation coefficients are barely significant in Bruce Peninsula. Elsewhere they are too small to be given much consideration. This suggests that August precipitation is significant in determining subsequent yields of oats only in regions where harvesting is late. In such counties as Muskoka and Parry Sound either short-season varieties like Alaska are sown, or else coefficients that were significant for the early part of the month have been masked by the neutral ones of the latter part. As in the case of August temperatures, meteorological data for weekly intervals are needed. From the evidence at hand we can only conclude that precipitations of August *as a whole* are of little importance in determining the yield of oats in Southern Ontario.

The Zonation of Oats

Figs. 14 and 15 each summarize five earlier maps, showing areas of significant coefficients for monthly temperatures and precipitations, respectively.

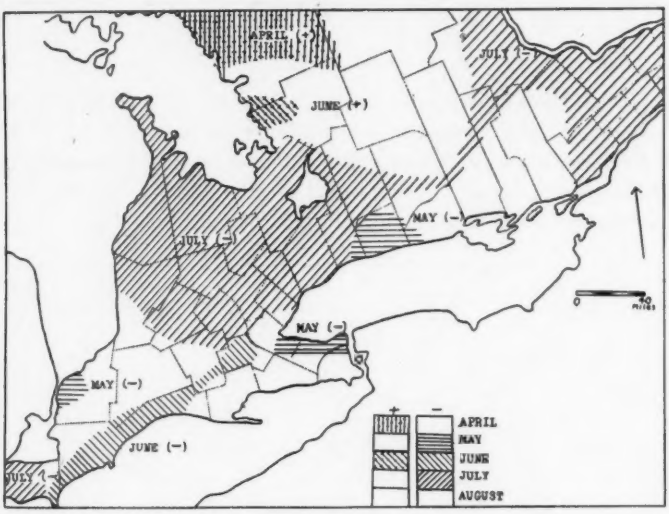

FIG. 14. *Summary map of significant correlations between oat yields and temperature (over 0.50).*

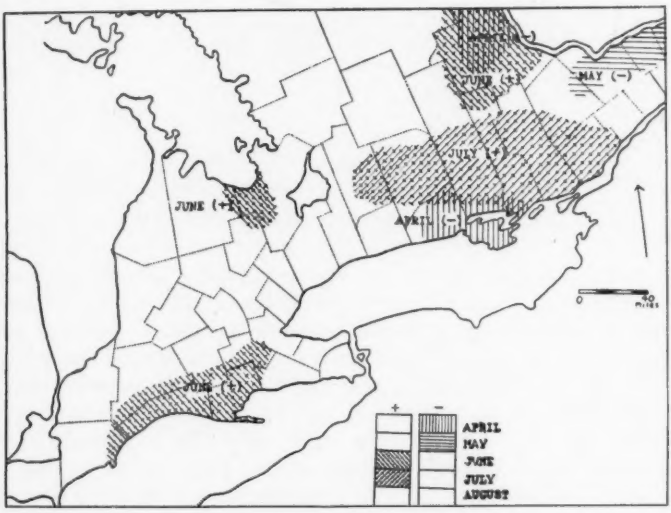

FIG. 15. *Summary map of significant correlations between oat yields and precipitation (over 0.50).*

The value ± .50 has been taken as the lower limit for significant correlation. By superposing such areas, the general effect of temperature and of precipitation throughout the growing season may be seen at a glance.

As far as temperature is concerned, July is the month of greatest significance throughout the central and eastern counties. This month should be below normal if heavy yields of oats are to be expected. Of less widespread importance are,—

(a) April temperatures in Parry Sound, which should be above normal.

(b) May temperatures in Welland, Durham, and Lambton, which should be below normal.

(c) June temperatures in Lake Erie counties and Muskoka, the former needing to be below normal, while the latter should be above normal for good yields.

(d) Temperatures for August as a whole are relatively unimportant.

Thus, as far as temperature is concerned, July is the critical month, coolness being necessary in most of the counties, while May and June tend in the same direction though less definitely so, except in Muskoka, where the oat crop is favoured by hot Junes. April temperatures are of chief importance in the coldest area, those above normal favouring high yields of oats. Thus, in general, temperatures below normal during the growing season are advantageous for oats.

As regards precipitation, June is the month in which significant coefficients are most widespread and when rainfalls greater than normal are needed. Of the other months, April needs to be drier than normal in the vicinity of Prince Edward county; May should be below the average in the eastern counties (which have a rather heavy precipitation); July, like June, should be wetter than usual in the central–eastern counties; while August is relatively unimportant for precipitation as it was for temperature.

In the region where July temperatures are the critical factor precipitation is, within limits, unimportant. Also, April temperature is the chief determining factor in Muskoka, i.e., the earlier the planting the better the yield, regardless of subsequent temperatures and precipitation.

The fact that, except for July temperature, there are no significant climatic factors in the vicinity of Wellington county, suggests the reason why Irvine (30) was disappointed in the low values obtained in his study of oats at the Ontario Agricultural College, Guelph. That is, the varieties used there are so well adapted to meteorological, soil, etc. conditions, that variations in temperature and precipitation are relatively unimportant.

These results are summarized in Table I and Fig. 16. The following description of the 13 regions involved in the present study is supplementary to that of Putnam and Chapman (34). The regions are considered in order from west to northeast, i.e., from those with the earliest, warmest, and longest growing seasons, to those that are less favoured in these respects.

TABLE I

REGIONAL DIVISIONS OF SOUTHERN ONTARIO (SEE FIG. 16)

—	Leamington	Niagara fruit belt	Kent and Essex	Lake Erie Counties	Lake Ontario Counties	Prince Edward County	Lake-Huron-Georgian-Bay	South slopes	Simcoe and Kawartha Lakes	Eastern Counties	Western upland	Muskoka	Renfrew
Altitude (ft.)	600	250 −400	600 −700	600 −800	250 −400	250 −400	600 −800	600 −1000	600 −1000	200 −400	1000 −1800	600 −900	400 −800
Oat yields (bu./ac.)	39	33	39	34	32	32	36	36	34	32	36	31	30
Oat yields (variability, %)	19	16	18	16	16	14	15	16	18	18	18	14	18
April temperature (° F.)	45	43	44	43	41	41	41	41	40	41	41	38	40
May temperature (° F.)	56	54	56	54	53	54	52	53	53	54	52	51	53
June temperature (° F.)	68	65	66	64	64	63	62	64	63	64	63	61	63
July temperature (° F.)	73	71	72	70	69	70	68	68	68	69	68	66	67
August temperature (° F.)	71	68	70	68	67	67	66	66	66	67	66	64	65
Variability (%)—April T.	6	5	6	6	6	6	7	7	7	7	7	8	7
Variability (%)—May T.	5	5	5	5	5	5	6	6	6	5	6	6	6
Variability (%)—June T.	5	4	5	4	4	4	4	4	4	4	5	4	3
Variability (%)—July T.	3	3	2	3	3	4	4	3	4	4	4	3	4
Variability (%)—August T.	3	3	2	3	3	3	3	3	3	3	3	4	3
r—April temperature	−.30	.30	−.30	.00	.00	−.20	.20	.00	.00	−.20	.00	.30	−.20
r—May temperature	−.10	−.70	−.20	−.30	−.40	−.40	−.30	−.40	−.40	−.30	−.30	−.30	−.20
r—June temperature	−.50	−.20	−.40	−.40	−.30	−.30	−.20	−.40	−.20	−.30	−.30	.40	−.20
r—July temperature	−.60	−.20	−.40	−.10	−.40	−.30	−.60	−.60	−.60	−.50	−.70	−.40	−.50
r—August temperature	.00	.10	−.10	.00	.00	−.10	−.20	−.10	.00	−.10	−.10	.10	−.10
April rainfall (in.)	2.8	2.7	3.1	3.1	2.6	2.5	2.6	3.0	2.5	2.9	2.6	2.6	2.6
May rainfall (in.)	2.1	2.3	2.4	2.6	2.3	2.2	2.7	2.6	2.4	2.8	2.8	2.7	2.4
June rainfall (in.)	2.8	2.9	2.6	2.9	2.8	2.8	3.0	3.0	2.9	3.2	3.0	3.3	3.0
July rainfall (in.)	2.2	2.9	2.5	2.8	3.0	2.3	3.1	3.0	3.0	3.0	3.1	3.0	2.8
August rainfall (in.)	2.1	2.2	2.2	2.4	2.5	2.3	2.3	2.6	2.5	2.8	2.5	2.4	2.4
Variability (%)—April rainfall	40	50	45	55	35	35	45	50	35	30	45	35	40
Variability (%)—May rainfall	40	50	50	50	50	40	50	50	50	50	40	50	40
Variability (%)—June rainfall	50	40	40	50	35	40	40	35	35	35	40	40	40
Variability (%)—July rainfall	60	60	60	60	50	40	50	50	40	40	50	35	40
Variability (%)—August rainfall	60	65	60	60	50	50	50	50	40	40	45	45	40
r—April rainfall	−.30	−.40	−.20	−.30	−.50	−.70	−.30	−.30	−.30	−.30	−.20	−.10	−.40
r—May rainfall	−.40	.00	−.30	.00	.20	−.10	−.20	.10	.10	−.40	−.20	.00	−.20
r—June rainfall	.30	.40	.40	.50	.20	.30	.30	.30	.20	.00	.30	.30	.50
r—July rainfall	−.10	.20	−.20	.00	.50	.40	.30	.40	.50	.50	.30	.10	.40
r—August rainfall	−.20	.10	−.10	.00	.00	.00	−.40	.10	−.20	.10	−.20	−.20	−.10

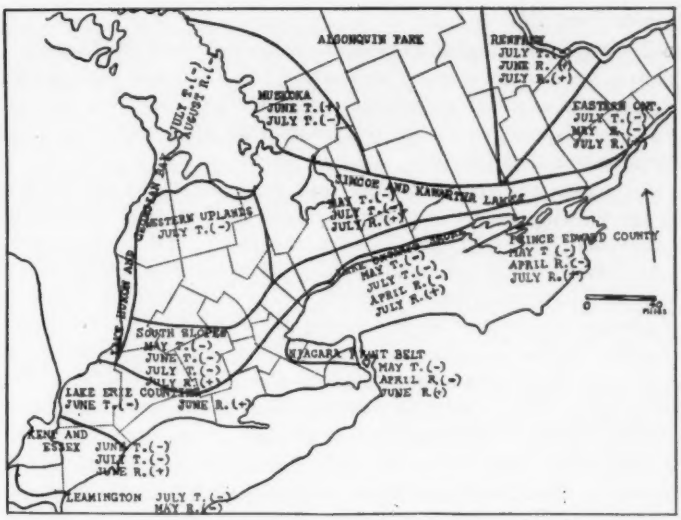

FIG. 16. *Significant periods (over 0.40) in climatic regions of Southern Ontario.*

1. *Leamington Area*

The chief characteristics of this region are,—it is small; it is the warmest area in Ontario and has the earliest spring; it is relatively dry, with high evaporation due to the accompanying high temperatures in summer. Its oat yields are among the highest in the province, but these exhibit greater variability than anywhere else. Its temperatures during the five months considered are higher than for the other areas. Of the correlation coefficients between yield and mean monthly temperatures, those for June and July are significantly negative, while the coefficient for August as a whole is of no significance. The early-maturing varieties of oats are used in this region, so that by August the crop has already been reaped, hence the low coefficient. In June and July the temperatures in this, the hottest part of the province, are normally too high to be favourable for oats. This fact was also brought out by the isopract method, described below.

The rainfall here is relatively low in each of the five months, the dryness being another reason for classing the area with the Corn Belt rather than with the greater part of Southern Ontario. The great variability of the rainfall is another characteristic of dry regions. The most significant correlation coefficient between yield and precipitation is that for May, it being negative since high yields accompany rainfalls that are below normal for that month. Thus the major factors for Leamington are June and July temperatures below normal.

2. *Niagara Fruit Belt*

This is also a small region, between Lake Ontario and the Niagara Cuesta. Its chief characteristics are temperatures ½° to 1° higher than those of the adjoining area above the Escarpment; the lack of extremely low temperatures, which is very favourable to the peach orchards, etc.; and low precipitation effectiveness as in Leamington.

Its oat yields are relatively low and very variable. Its temperatures during the growing season are slightly cooler than those in Leamington, but these are even more reliable than for the latter. Of the correlation coefficients between yield and monthly mean temperatures, the one for May is the only significant one, being negative. May temperatures (below normal) are of greater importance in this region than in any of the others. As in Leamington, August temperatures are relatively unimportant in determining yields of oats there. Also, since climate and soil are ideal for fruit in the Niagara region, oats are relatively unimportant there, preference being given to the better paying crops, peaches and grapes.

This region is generally wetter than Leamington, and its variability is even greater. The coefficients between yield and precipitation are generally positive for this area, except in April. However, the only really significant factor is May temperature.

3. *Kent and Essex Counties*

This region of low relief has the following important characteristics,—it is slightly cooler than Leamington but warmer than the Niagara area; extreme, low temperatures and high range, as well as heavy clay soils limit the tender fruits in this region; precipitation effectiveness is low here, too. Its oat yields are among the highest in the province, with high variability in them, however. The mean monthly temperatures, which are very reliable, are intermediate in value between those of Leamington and those of the Niagara Fruit Belt. Of the correlation coefficients between yield and monthly mean temperatures, those for June and July are the most significantly negative, though less so than in Leamington. That is, in the cooler regions these warm months are of less importance in determining the yield of oats. In the other months temperatures are relatively unimportant.

It is generally wetter than Leamington, but its western portion is still dry enough to merit inclusion with the Corn Belt rather than with other parts of Ontario. It is the chief husking corn area in the province. As regards precipitation, the coefficient for June is the highest and only significant one; it is positive as for the rest of the region. In the other months precipitation below normal presages a good crop of oats, though not significantly so. June and July temperatures and June precipitation are the most critical factors here.

4. *Lake Erie Counties*

This region is greatly affected by the proximity of the three Great Lakes, Huron, Erie, and Ontario, especially as regards temperature range, frost dates, and length of the growing season (Fig. 16).

Its yields of oats are considerably less than in the two regions to the west of it, but slightly higher than in Niagara. However, the yields are considerably more reliable in this case. Of the correlation coefficients between yield and mean monthly temperatures, the value for June is the most significant, cool Junes being needed. The extremely low values for April and August suggest that in this region it is particularly important that data for periods shorter than a month be available, especially at the beginning and end of the growing season.

It is somewhat wetter than Kent–Essex, but the variability of the precipitation is also greater. As to coefficients between yield and precipitation, the value for June is the only significant one and is positive. Thus both temperature and precipitation in June are critical factors, cool wet conditions foreshadowing high yields.

5. *Lake Ontario Shore*

The effect of Lake Ontario is felt for a relatively short distance inland, compared to the zone of influence of Lake Erie. Its chief characteristics are relatively small ranges of temperature and a longer frost-free period than in the regions farther from the lake. Here, too, the precipitation efficiency index is fairly low.

The oat yields are lower than in any of the foregoing regions, but they are fairly reliable. Temperatures are slightly cooler than those near Lake Erie. Of the correlation coefficients between yield and mean monthly temperatures, those for May and July are the most important, these being negative. In general, temperatures below normal favour the yield of oats.

The precipitation is somewhat lighter than in the Lake Erie counties, but its variability is definitely lower. The coefficients between yield and precipitation are most important in April (negative) and July (positive), showing the importance of drier than normal conditions at seeding time, with heavier than average precipitation later on. Thus for the Lake Ontario Shore precipitation would seem to be more important than temperature, particularly in April and July.

6. *Prince Edward County*

This area has a more decided marine position than any other part of Ontario. Its chief characteristics are similar to those of the Lake Ontario Shore as far as temperature is concerned, but as regards precipitation, it is one of the driest regions in Ontario, and as well has the lowest precipitation effectiveness index.

Its oat yields are similar to those for the Lake Ontario counties but they are more reliable than the latter. It is about 1° warmer than the region to the north of it. Of the correlation coefficients between yield and mean monthly temperatures, the May value (negative) is the only fairly important one, the others all being negative but of small magnitude. All, however, show that cool seasons presage high yields of oats there.

The rainfall is one of the lowest in Southern Ontario, however, it is more reliable than in the dry area of Leamington. As to the coefficients between yield and precipitation, the most significant value is that for April (negative). The figure for June (positive) is also fairly important, and indicates the need for heavy precipitation in that month. Thus for Prince Edward county the critical factors are,—May temperature, and April and July precipitation.

7. *Lake-Huron–Georgian-Bay*

This is a narrow region along the Lake Huron and Georgian Bay shore, and is demarcated by the influence of the adjacent bodies of water. It is similar to the Lake Ontario area, but slightly cooler (Fig. 16).

The oat yields here are higher than for Lake Ontario or Prince Edward areas. The region is slightly cooler, however, than is Prince Edward county. Of the coefficients between yield and monthly mean temperatures, that for July is the important one (negative). In general, temperatures below normal are favourable for high yields of oats in this region.

The rainfall is generally higher than in Prince Edward, but is somewhat less reliable here. As to the coefficients between yield and precipitation, the most significant factor is the one for August (negative), the other values being too small to be significant.

Thus July temperature and August precipitation are the critical factors, both of which should be below normal for high yields of oats.

8. *South Slopes*

This region is milder than the one to the north, but is relatively unaffected by the ameliorating influences of Lakes Ontario and Erie (Fig. 16). The oat yields are similar to those for the Lake-Huron–Georgian-Bay region. The temperatures too are almost identical. Of the correlation coefficients between yields and monthly mean temperatures, the one for July (negative) is the most critical. The figures for May and June, also negative, are fairly important, too.

The precipitation in this area is somewhat more uniform than in the areas discussed above. As to the coefficients between yield and precipitation, the most significant figure (positive) occurs in July. All the other months, except April, have positive coefficients, suggesting the need for precipitation above the normal in each month except the first. Thus for the South Slopes area temperatures in May, June, and July and the precipitation in July are relatively important. The former should be below normal and the latter above normal to presage high yields of oats.

9. *Simcoe and Kawartha Lakes*

This region is colder generally than the foregoing areas. Precipitation is somewhat lighter than in the Western Uplands, since that area creates a 'rain-shadow' effect in the Simcoe and Kawartha Lakes region.

The oat yield is somewhat lighter than in the above areas, and it is more variable. Temperatures are slightly cooler. Of the correlation coefficients

between yields and mean monthly temperatures, the July value (negative) is the critical one, while that for May (negative) is fairly significant.

The rainfall here is somewhat less than for regions to the south and west, largely owing to topographic conditions. It is likewise less reliable than in the Western Uplands and South Slopes regions. Of the coefficients between yield and precipitation, that for July (positive) is the most important. Thus for this area, temperatures below normal in May and July, and precipitation above normal in July are favourable for high yields of oats.

10. *Eastern Ontario*

This is a low region of gentle relief similar in climate to the contiguous area of Quebec. It is characterized by extreme temperatures and heavy precipitation with little likelihood of drought. The oat yields are relatively low and very variable. Temperatures are slightly higher than in the Simcoe and Kawartha Lakes region. It is interesting to note that in this area, as in each of the others, the variability of the mean monthly temperature decreases as the season advances. Of the correlation coefficients between yield and monthly mean temperatures all are negative, but the only significant one is that for July.

The rainfall of Eastern Ontario is the heaviest in the whole area for the growing months. It is also much more uniform than elsewhere in Southern Ontario. Precipitation is more important in May (negative) and July (positive). Thus the early part of the growing season is favoured when precipitation is below normal and the latter part is above normal, while June as a whole has very little effect.

For the Eastern Counties then, temperatures below normal for July are the most important factor in determining high yields of oats.

11. *Western Uplands*

This is the highest part of Southern Ontario, with fairly steep slopes on the north and east (Fig. 16). It is moderately humid, with heavy rainfall and cooling effects largely determined by its altitude. Here the oat yields are fairly high. Temperatures are very similar to those of the Simcoe and Kawartha Lakes region. As regards coefficients between yield and mean monthly temperatures, the one for July (negative) is the only important one.

Precipitation here is fairly heavy, but not as high as that in the Eastern Counties. As to the coefficients between yield and precipitation, there are none of real significance, the highest being $+.30$ in June and July. All the others are negative but of small magnitude. Thus in the Western Uplands the only critical factor is July temperature, which should be below normal to presage high yields of oats.

12. *Muskoka*

This region is fairly far north, but its climate is ameliorated by the proximity of Georgian Bay. Temperatures during the growing season are lower than those for Renfrew. Its precipitation is fairly heavy. The oat yields here are

almost the lowest in Southern Ontario, only those of Renfrew being lower, probably due to the soils. However, the yields are considerably more constant in Muskoka than in Renfrew. It is some 2° cooler than Renfrew. Of the correlation coefficients between yield and monthly mean temperatures, the most important ones are those for June (positive) and July (negative), suggesting that warm Junes and cool Julys favour subsequent high yields of oats.

The precipitation is somewhat heavier than in the region to the south and in Renfrew, except at the beginning and end of the growing season. The coefficients between yield and precipitation in Muskoka are too small to be considered significant, the highest one being +.30 in June. Thus the critical factors in Muskoka would appear to be the temperatures during June and July, rather than the precipitation there.

13. *Renfrew*

This is a relatively narrow depression in the Canadian Shield. The dominant influence on the climate here is the high regions nearby. There is a great tendency to extremes in temperature. It experiences a moderate rainfall.

The oat yield is the lowest of any region in Southern Ontario, and this is very variable. The temperatures are about 2° higher than in Muskoka during the growing season, largely because it is an inland area without the ameliorating effect of Georgian Bay enjoyed by Muskoka. The coefficient between yield and temperature is significant in July (negative). Thus, in this cool region too, temperatures below normal during the growing season are favourable for the growth of oats.

Precipitation is somewhat lighter than in Muskoka except at the beginning and end of the growing season. As to the coefficients between yield and precipitation, the most significant value is that for June (positive). April (negative) and July (positive) are also fairly important. In Renfrew, therefore, July temperatures and April precipitation below normal, and June and July precipitations above normal presage high yields of oats.

Isopracts Relating Oats and Climate in Southern Ontario

In order to test the validity of the correlation method a second technique known as the isopract method was carried out.

This graphical technique is based on the climograph invented by Griffith Taylor, and extended by Ellsworth Huntington (28, Chap. 4) to apply to yields of crops. Isopleths (lines of equal distribution) of yields are drawn joining all points of given yield per acre for different combinations of monthly temperature and precipitation. It is thus possible to define the optimum conditions of temperature and rainfall in the given month for the particular crop.

As Huntington suggests, "a farm with good soil or good cultivation and optimum weather may average 45 bushels per acre, whereas another with poor soil or poor cultivation and the same weather may produce only 25. But we

are talking about averages for many different years and for many different counties."

Thus an isopleth map like Fig. 2 shows the location of the optimum conditions for oats when soil, topography, etc. are involved, while the isopracts in Fig. 17 show the ideal conditions of climate only, for this crop. Both illustrate the fact that yield declines as the conditions of growth depart from the optimum ones.

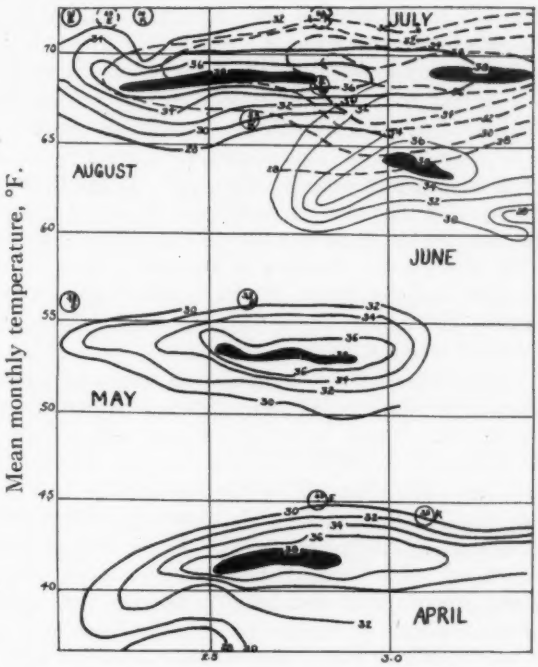

FIG. 17. *Oat-yields–climate isopracts (K = Kent: E = Essex).*

The optimum conditions are as follows:

Month	Precipitation (in.)	Temperature (° F.)
April	2.5 to 2.9	41 to 43
May	2.5 to 2.9	53 to 54
June	3.0 to 3.2	63 to 65
July	3.1 to 3.4	68 to 69
August	2.2 to 2.9	68 to 69

The diagrams suggest that the precipitations for June and July are decisive factors, while those for April, May, and most of all for August, are relatively unimportant; i.e., for August a rainfall of anywhere from 2.2 to 2.9 in. may give optimum yields, provided that temperatures are suitable. This is brought out in the figure by the wide extent (in precipitation) of the black portion of the August isopract. When we examine the correlation coefficients the above facts are corroborated, the values being greatest for June and July, i.e., when the possible range for ideal yields is least. The August data, too, bear this out since the coefficients are low when the isopracts show a great extent in precipitation for optimum yields.

In the case of temperatures, July is the critical month, shown by the relatively narrow extent in temperature (range between maximum and minimum). This again agrees with the conclusions reached by the correlation method.

Another point of interest noticeable on the graphs is that Essex and Kent (known to be the major husking corn region in Ontario) do not fit the isopracts for any of the five months. i.e., these two counties have conditions so different from the rest of the region that one would recommend classing them with the warmer, drier Corn Belt of the United States to which they are contiguous. This fact may account for some of the extreme values of the correlation coefficients found for this region earlier in this study.

The isopract method thus gives a quick visual suggestion of the more accurate conclusions attainable by the more laborious correlation coefficient method.

Conclusions

The results of Irvine (30), who studied the growth of oats at the Ontario Agricultural College in Guelph, have been shown to agree fairly well with the ones obtained in the present study. Hooker (13, 14), dealing with the eastern coast of England, found the 17th to 24th and 21st to 28th weeks of high positive significance, i.e., roughly April-May and May-June temperatures should be below normal, but the precipitations should be above normal to be followed by high yields of oats. The critical period is thus earlier in England than the general one for Ontario. This is, of course, what the marine climate of eastern England would suggest. Geddes (11), in studying the northeast of Scotland, found the only significant factors were total accumulated temperatures above 42° F., these being positive. That is, in this region the temperatures for the 10th to 18th weeks (roughly mid-March to mid-June) should be above normal for high yields. As this phase has not been dealt with in the present study it cannot be compared with the results for Southern Ontario. His total coefficients of yield–precipitation data were too small to be assigned any weight. Roberts (35) studying oats at Bangor, Wales, established no correlation between yield and total rainfall or total accumulated temperatures for the growing season. The above three regional studies are set forth here to show the wide variety of results over these areas of Great Britain. It is not surprising, then, to find similar variety in the

different counties of Southern Ontario. Smith's results (39) for United States corroborate this evidence of change of critical factors with change of locality.

In general, the results of this study would lead us to believe that weather factors for long periods have not as great an effect on the yield of oats as one might expect. The reason for this, of course, is that while the first half of a month may show a positive correlation, this may be neutralized by a negative effect in the latter half of this period. It is suggested, therefore, that meteorological data for at least 15-day periods or, better still, for 10-day or even 5-day intervals be made available. This is particularly necessary at the beginning and end of the growing season. Another definite need is phenological data as to periods of sowing, germinating, stooling, heading, and ripening of the grain. In addition, yields for units smaller than the county are necessary.

The writer is aware that 17 years forms but an inadequate period of observation for such a study on statistical lines. It is hoped, however, that the tentative findings put forward will justify the work in that they have pointed to, and defined, critical factors that can be observed more closely in future years.

The peculiar position of some of the meteorological stations may account for the fact that their counties often show up on the maps of correlation coefficients as isolated islands. For some of these isolations the writer can find no explanation unless it be some peculiarity in the location of the weather station, or possibly in the data recorded. Also the lack of continuity at certain stations may introduce spurious effects. Even though the areal distribution pattern of some correlation coefficients is not explained or seemingly explainable, such patterns are presented in order that they may perhaps prove the basis of further study.

Time of seeding has an important effect on productivity. In general, seeding of oats in Ontario takes place from April 15 to May 25, depending upon districts and seasons. That delays in seeding have a marked effect upon yields is generally recognized by farmers and is very definitely proved by field trials. While phenological data were inadequate for detailed study, the adverse effect of heavy precipitation or of low temperatures during April and May in the Niagara Fruit Belt, for example, may be due to the fact that these factors result in delayed seeding. This illustrates the need for more exact phenological data before more definite conclusions can be reached on this subject.

Despite its drawbacks, the method of correlation coefficients between oat yields and climate in Southern Ontario has suggested that several important environmental factors are in operation there. Varieties are chosen according to the length of the growing season, particularly in the northern areas of Muskoka where this is short, and in the southern regions of Leamington and Essex–Kent where the possibility of heat waves constitutes a definite menace to the success of the crop. Soil conditions are favourable in most areas, since clays and clay loams predominate. However, the sandy soils of Norfolk

county are poor for oats since they fail to hold moisture, so that little of this crop is grown. Likewise in Renfrew and Muskoka areas the soil is the dominant factor. There the podsolized and thin layer over the rock knob is not rich enough for any grain crop other than oats and buckwheat. Thus while the yield of oats is poor, it is practically the only choice for the farmer.

In Essex–Kent and Leamington, which have been shown to be closely linked with the warm, dry American Corn Belt, we find the chief area of husking corn in Ontario. Thus here, as in United States, the overlap of the oat and corn belts is noticeable.

Topography and climate make the Niagara region ideal for fruit, so that oats, which are of lower cash value, are practically non-existent there. This is a dominantly economic factor, ultimately dependent on topography and climate.

Certain varieties are relatively unaffected by precipitation and temperature. Counties using varieties best adapted to their conditions of climate exhibit low correlation coefficients. The conclusion is therefore reached that such regions as the Southern Slopes and the Lake Ontario Shore, which exhibited many significant coefficients, may give higher yields if and when new strains of oats better suited to their environmental conditions are developed, or possibly if methods of cultivation and treatment of plant diseases are improved.

In conclusion, the following suggestions may prove helpful for future work on oats:

Varieties more suitable to the poor soils of Muskoka and Renfrew are needed. One cannot recommend abandoning this crop there, although it is possible that future development of the Clay Belt of Northern Ontario, which has much better soils for oats, may make this advisable, particularly if transportation can be arranged economically.

The plea for reliable crop statistics for townships in which meteorological stations of long standing exist, is repeated here. Also the need for climatological data for 5- or 10-day intervals, as well as phenological information is again stressed.

Throughout this study several suggestions have been made as to requirements for future work on oats, viz., more accurate meteorological, phenological, pedological, and agronomic information are necessary. These will require the combined efforts of specialists in these subjects, but the geographer's part will be to apply correlation methods (partial and multiple as well as the simple ones used here) to the data obtained. As the result of such study it should be possible to formulate a system of zoning for the varieties of oats used in Southern Ontario, and to recommend the abandonment of those varieties now used in certain areas in favour of others better suited to the soil and climate there It is hoped that this paper will prove some incentive to those concerned to work towards this goal.

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THE FLUORESCENCE OF FROZEN POTATO TUBER AND APPLE FRUIT TISSUE UNDER ULTRA-VIOLET LIGHT[1]

By W. Newton[2] and W. Jones[3]

Abstract

Freshly cut sections of frozen potato tuber and apple fruit tissue exhibit a brilliant fluorescence when examined in a dark room under an ultra-violet (Stroblite) lamp. The fluorescence disappears from the apple tissue upon thawing but is retained in potato tuber tissue. Thus the ultra-violet lamp serves as a useful diagnostic means of detecting frost or low temperature injury in potato tubers. Many other plant tissues were frozen and examined, but proved to be non-fluorescent. Acetone extracts of both normal and frozen potato tuber tissue were fluorescent, but similar extracts of both frozen and normal apple fruit were not. Although normal potato tissue is non-fluorescent and frozen tissue is brightly fluorescent, no differences were found in the brightness of the acetone extracts.

Last winter the junior author observed that frozen potato tuber tissue exhibited a brilliant fluorescence when freshly cut sections were examined under an ultra-violet lamp in a dark room. Furthermore, in the course of routine examinations of tubers for bacterial ring rot, cross sections of a sample were brilliantly fluorescent, yet a microscopic examination showed that the ring rot organism, *Corynebacterium sepedonicum* (Spieck. & Kott.) Skapt. & Burkh., was not present. In the absence of the ring rot organism, tuber tissue invaded with *Pythium* and *Fusarium* spp. is frequently fluorescent at room temperatures, and, conversely, rare cases have been found of non-fluorescence at room temperature when the ring rot organism was present. However, the case under study differed from previous examples in that the tissue, although soft, appeared to be free from fungi and practically free from bacteria. In all previous cases where tuber tissue was fluorescent under the ultra-violet lamp, the tissue was found to be invaded with bacteria or fungi. Since the sample bore symptoms of frost injury, an uninjured sample of tubers was rapidly frozen and the tissue immediately became fluorescent.

Practically all pathologists who have used the ultra-violet lamp as a means of detecting ring rot infection in potatoes have noted fluorescence due to other causes and, although cases of fluorescence due to wounds, bruises, and other types of injury have been cited (1, 4), the evidence has not excluded an invasion by secondary organisms as the cause. Kreutzer and McLean (2) found that fluorescence due to ring rot was more constant when the tubers were stored at 40° F. than when stored at 70° F. but apparently they did not extend their investigations to cover temperatures near or below the freezing point.

[1] *Manuscript received January 8, 1945.*

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Experimental

The following plant tissues were frozen for 24 hr. at −10° C. and corresponding tissues were maintained for the same period at 5° C. and at room temperature: potato tuber, green potato haulms, apple fruit, apple twigs from branch extremities, green pepper fruit, pepper haulms, cherry twigs, and tips of raspberry canes. Subsequently, freshly cut sections from these tissues were examined for fluorescence under a Stroblite ultra-violet lamp. In the frozen state both potato tuber and apple fruit tissue exhibited a brilliant fluorescence, but the other tissues did not become fluorescent. The potato tuber tissue maintained for 24 hr. at 5° C. became slightly fluorescent, but the intensity was of a minor order compared with that induced by freezing. Apple fruit tissue was not fluorescent after being stored for 24 hr. at 5° C. After thawing the potato tissue retained its fluorescence, confirming the original observation that, when potato tissue is fluorescent under an ultra-violet light and no evidence of bacterial or fungus injury can be found, it may be assumed that the tubers have been frozen or subjected to abnormally low storage temperatures. The fluorescence of frozen apple fruit tissue disappeared upon thawing the tissue. None of the tissues referred to in this study were fluorescent either before or after storage at room temperature.

The potato tuber and apple fruit tissue were extracted in both their frozen and normal states with acetone. The acetone extracts of both frozen and normal potato tuber tissue were fluorescent, but, contrary to expectations, the acetone extracts of frozen tubers were no more fluorescent than the extracts of normal tuber tissue. In the original trials a greater amount of the fluorescent substance was obtained from the frozen tubers, but, when corresponding amounts of frozen and normal tissue were thoroughly ground with acetone in a mortar, the filtrates showed no visible difference in fluorescence. Neither of the acetone extracts of frozen or normal apple tissue showed any fluorescence.

Discussion

There appeared to be the possibility that the fluorescence of potato tuber tissue invaded with the ring rot organism, *C. sepedonicum*, might be due to the release of fluorescent substances already present in the potato, in a manner similar to the induction of fluorescence by freezing, rather than to the synthesis of riboflavin or other fluorescent substances by the organism. Although such a possibility still exists, nevertheless, the evidence suggests that a fluorescent substance is synthesized by the ring rot organism. First, Skaptason (3) has shown that a greater amount of the fluorescent substance can be extracted by acetone from ring rot invaded tissue than from normal tuber tissue. Since we were unable to extract more fluorescent material from frozen than from normal tissue, this suggests that the fluorescence in potato tubers due to ring rot is caused by the synthesis of a fluorescent compound by the organism and is distinct from the fluorescence due to freezing. Second, Skaptason has shown that the ring rot organism appears to synthesize riboflavin, a fluorescent substance, when grown in a riboflavin-free medium. Third, he has

shown also that the organism exhibited a marked greenish fluorescence when grown *in vitro*. Our own studies showed that, when *C. sepedonicum* is grown in a non-fluorescent liquid potato dextrose medium, the cultures often become fluorescent when examined under the ultra-violet lamp.

No explanation can be offered yet as to why frozen potato tuber and apple fruit tissue become fluorescent under an ultra-violet lamp or why, after they thaw, the fluorescence is retained in potato tuber tissue but disappears in apple tissue. If, in potato, the fluorescence is due to a substance that can be extracted by acetone from potato tubers, then the freezing must allow the substance to diffuse out of the cells, for normal potato tissue is not fluorescent. If the fluorescence of frozen apple tissue is due to the same substance, then this compound must be present in much smaller amounts than in potato tissue, for acetone extracts of apple fruit tissue were non-fluorescent and the fluorescence of the frozen tissue disappeared with great rapidity when the tissue thawed.

The fluorescence of potato tuber tissue resulting from freezing or storage at temperatures close to the freezing point has proved to be a useful laboratory diagnostic method. By means of the ultra-violet lamp, it is frequently possible to distinguish frost from mechanical injury and to establish whether the sweet taste of certain potato lots is due to long periods of storage at temperatures close to the freezing point rather than to immaturity or other causes.

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